# GridWorks

*RD&D Planning Workshop*

CHICAGO, ILLINOIS

OCTOBER 20-21, 2004

WEBCAST

OCTOBER 27-NOVEMBER 3, 2004

**"Research Pathways to the Next Generation of Equipment for Substations and the Grid"**

## -- DRAFT --

# Workshop Proceedings

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# EXECUTIVE SUMMARY

Modernization of the North American electric grid is a critical, national energy priority. **"GridWorks"** is a new program designed to research, develop, and demonstrate improved technologies for power cables and conductors, substation equipment and protective systems, and power electronics devices.[1]

A planning workshop was held to identify technology needs and priorities for the GridWorks program.[2] Over 160 participants from electric utilities, equipment manufacturers, state and federal agencies, universities, and national laboratories either attended the onsite component or participated in a webcast to discuss electric reliability and grid modernization, advanced technologies, and potential "paths forward" for addressing grid modernization challenges and opportunities.

The following is a summary of the major findings and conclusions of these discussions.

### Concerns about Electric Reliability and Grid Modernization

- Today, America's electricity consumers are served by a vast network of power lines, transformers, and substations, a substantial portion of which have been in use for thirty years or longer. Incomplete efforts to restructure electric markets and regulations across the country have led to uncertainty about financial attractiveness and cost recovery for investments in modernized electric infrastructure. The result has been a rise in reliability "events," including both local and regional blackouts, with economic losses in productivity and profits, and threats to public health, safety, and security.
- Despite this, it has been difficult to sustain the interest and commitment of public- and private-sector decision makers to do something about electric reliability problems and the need for grid modernization. For example, the stalemate in the U.S. Congress regarding national electricity legislation has prevented reforms from being enacted that could reduce certain regulatory uncertainties and increase the financial attractiveness of investment in electric transmission and distribution.

[1] Funding for the GridWorks program is contained in the fiscal year 2005 budget request for the U.S. Department of Energy. The scope of the proposed activities is based on the suggestions contained in the *National Electric Delivery Technologies Roadmap*, January 2004, which can be downloaded from www.electricity.doe.gov.

[2] The workshop was sponsored by the U.S. Department of Energy, Office of Electric Transmission and Distribution and facilitated by Energetics, Incorporated. The Workshop was held in Chicago, Illinois on October 20-21, 2004.

- Looking to the future, growth in electric demand, coupled with expanding needs for higher reliability and better power quality, is expected to mean even more strain on the electric system, and perhaps increase the likelihood of outages and power quality disturbances. In addition, public awareness and concern is growing about the consequences of America's aging electric infrastructure for economic growth and development, the security of key electric assets, and their resilience to terrorist attacks.
- Existing levels of funding for research, development, and demonstration of advanced grid technologies to improve reliability and modernize the grid are not sufficient to meet the need.

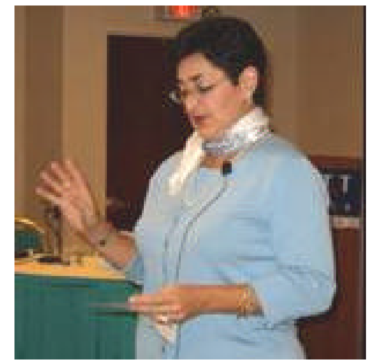
### "Top Priority" GridWorks Technology Development Needs

- There is a need to increase the electric capacity of existing transmission corridors, either by incrementally improving existing lines with traditional technologies or through the development of advanced cables and conductors that can operate at higher temperatures and with less sag, and that have built-in sensors for detecting and communicating problems before they result in system disturbances or outages. There is also a need to explore lower-cost techniques for digging trenches and remote diagnostics for the underground installation of electric cables and conductors.
- There is a need to expand the functionality and improve the performance of electric substations and protective systems. Improved operational and diagnostic support tools can strengthen asset management. New designs for substations should include international standards and protocols for product performance, and modularity for greater flexibility. Designs need to include methods for cyber security and more reliable supervisory controls. Better transformers and fault current limiters would improve reliability and asset utilization.
- There is a need to accelerate the development of power electronics, lower their costs, and improve their performance. Power electronics devices hold substantial promise for transforming the electric power system. For example, in the near-term, the concept of a grid "shock absorber" could allow power electronics devices for the grid to respond better to large power oscillations and achieve better fault current management. In the long-term, there is need to investigate advanced materials ("beyond silicon") for power electronics switches, modular "building block" converter devices, and solid-state transformers. These devices would be designed to have the capability for high voltage, high frequency, high current, and high power density operations, with little or no cooling requirements and a favorable cost-to-value relationship.

### Paths Forward

- Striking the proper balance among the activities to address both near- and long-term needs is paramount for the GridWorks program to be successful. For example, there are improved versions of existing equipment that have not gained market acceptance due to insufficient field testing and demonstration. In addition, there are fundamental research opportunities to develop advanced materials for electric power applications – e.g., alloys, ceramic composites, and diamonds – that could revolutionize electric equipment and system operations. The GridWorks portfolio should include support for both near-term and long-term activities, funds permitting.

- Effort is needed immediately to expand and accelerate field testing and the demonstration of new or improved technologies in real-world environments. Utilities can support this effort by working with manufacturers and serving as "hosts" for field test projects, and then participating in disseminating information about lessons-learned, benefits, and pitfalls. The U.S. DOE should continue its support for testing facilities such as the National Transmission Technology Research Center at Oak Ridge National Laboratory and should consider supporting the development of a National Power Electronics Test Facility at a university or national laboratory.
- Effort is also needed immediately to develop an inventory of existing research, development, and demonstration projects at utilities, manufacturers, national laboratories, and elsewhere related to GridWorks technologies. This inventory will help verify the technology needs and priorities identified at the workshop, and help determine where limited federal resources can be applied to have the greatest impact.
- There is a substantial unmet need for long-term research and development in grid modernization technologies. The research supported by the U.S. DOE in high-temperature superconducting materials is very promising and needs to move forward. In addition, research to develop advanced materials needs to be accelerated, particularly for power electronics devices, but also for cables and conductors, transformers, and dielectrics. GridWorks should focus a portion of its resources on advanced materials development and other long-term research and development activities.



- All of the parties interested in grid modernization and advanced GridWorks technologies need to strengthen their coordination efforts to pool resources and leverage scarce research and development funding. In addition, a collaborative effort needs to be mounted to provide information to decision makers – federal and state, public and private – about the urgent need for action to modernize the grid and the significant costs to the economy, public health and safety, and homeland security from inaction. Efforts to coordinate more closely with complementary programs such as GridWise and the Office of Energy Assurance should be expanded.

# CHAPTER 1. INTRODUCTION


The U.S. Department of Energy's Office of Electric Transmission and Distribution sponsored the GridWorks RD&D workshop to gather stakeholders' input on technology needs and priorities for the GridWorks program. The workshop consisted of an onsite meeting held in Chicago, Illinois on October 20-21, 2004 and a webcast that was available October 27-November 3, 2004. 163 stakeholders from electric utilities, equipment manufacturers, state agencies, universities, national laboratories, and consulting and A&E firms participated in the workshop.

During the workshop, U.S. Department of Energy officials discussed program goals and the policy context for those goals. Additionally, there were three panels of speakers that focused on today's state-of-the-art technology in the following areas: 1) cables and conductors, 2) power electronics, and 3) substations and protective equipment. For each panel, a representative from the utility industry offered a perspective on the existing equipment that comprises the grid today and the functional requirements for that equipment; a representative from an equipment manufacturer offered a perspective on the costs and performance of existing products and services; and a representative from a national laboratory or university offered a perspective on the status of existing research and development.


During the first part of the workshop, participants provided input on the "drivers" affecting future grid operations and planning. The next part of the workshop focused on the technical needs and priorities for electric delivery equipment for improving the reliability, security, and affordability of electric system operations and planning. Both high priority and low priority needs were considered.

The workshop was designed to: (1) establish an effective research planning framework; (2) ensure program activities address top priority needs, as identified by utility organizations and others in the electric delivery community; (3) raise awareness about the Office of Electric Transmission and Distribution in general, and the GridWorks program in particular; and (4) build channels for effective coordination and communication about research needs, opportunities, and developments for electric grid technologies.

This document provides a summary of major issues presented during the panel sessions and captures the primary actions recommended by workshop participants.

# CHAPTER 2. “DRIVERS” AFFECTING FUTURE GRID OPERATIONS AND PLANNING

The future of electric system planning, operations, and grid modernization in the U.S. is highly uncertain. There is a range of future conditions and possibilities and a number of key factors which will drive decision making in the industry over the next several years. Drivers that support grid modernization include increasing needs for securing electric assets from terrorist attacks, growing customer demands for electricity and higher reliability and power quality, enactment of federal energy legislation, and another major regional blackout. Drivers that inhibit grid modernization include NIMBY (“not in my backyard”) is making it difficult to construct new transmission lines; research, development, and demonstration budgets for new electric technologies, tools, and techniques are not sufficient to meet the needs; and risk-aversion among electric power industry decision makers and regulators continues to be a force stifling innovation and a major cause of inaction.

A summary of the key drivers affecting future grid operations and planning is listed below in Table 1.

### TABLE 1. “DRIVERS” AFFECTING FUTURE GRID OPERATIONS AND PLANNING

| SUPPORTING GRID MODERNIZATION | BOTH SUPPORTING AND INHIBITING | INHIBITING GRID MODERNIZATION |
|---|---|---|
| ▪ Demand for change after the next blackout<br>▪ Customer needs for increased reliability, power quality, and services<br>▪ Homeland security, energy security, and physical/cyber security<br>▪ Passing of a national energy bill/policy<br>▪ Increasing load growth<br>▪ Declining load factors<br>▪ Technology breakthroughs that enable distributed intelligent networks to transform power systems<br>• Aging infrastructure and workforce | ▪ Competitive energy markets<br>▪ Asset utilization<br>▪ RTO/ISO role in regional markets and decision making<br>▪ Standardization<br>• Investment climate and ability to attract capital | ▪ NIMBY; difficult to site power lines and other facilities<br>▪ Inaction driven by fear<br>▪ Lack of willingness to pay for reliability<br>▪ Lack of money for RD&D<br>• Integrating advanced technologies (digital) with older technologies (analog) |

# CHAPTER 3. CABLES AND CONDUCTORS BREAKOUT SESSION RESULTS

Today's transmission system is being operated at power flow levels that reach the voltage, stability, and thermal limits of the cables and conductors. Transmission constraints and instabilities can cause negative impacts on the entire power system. Transmission lines require endurance against higher electrical and mechanical stresses in order to maintain the reliability of system operations.


Greater demands on the transmission system require greater power transfer capabilities, more capacity, and greater flexibility. Investment in the transmission system has been minimal and is lagging investments made in generation assets. Other challenges include difficulties obtaining new rights-of-way or expanding capacity in existing rights-of-way. Since most U.S. transmission is overhead, thermal limitations of sag is the major focus. Business drivers for overhead transmission include safety, reliability, longevity, and cost.

The standard, most common, overhead conductor that serves as the basis for comparisons is Aluminum Conductor Steel Reinforced (ACSR). Below are performance comparisons of existing conductor products.

| | PRODUCT | | | |
|---|---|---|---|---|
| CRITERIA | ACSR | ALUMINUM CONDUCTOR STEEL SUPPORTED | ALUMINUM CONDUCTOR COMPOSITE CORE | POLYMER CARLENE FIBER COMPOSITE |
| Rated Ampacity | 905 Amps | 2 x ACSR | 2.2 x ACSR | 2.1 x ACSR |
| Max. Operating Temperature | 75°C | 250°C | 240°C | 200°C |
| Sag | 0.125 ft/°C | 0.125 ft/°C | 0.04 ft/°C | <0.04 ft/°C |
| Cost (Est). | 1 x ACSR | 1.2 x ACSR | | 5 x ACSR |

Research is needed in cost-effective, high temperature, low-sag overhead conductors that can increase the capacity of our current infrastructure.

Underground electrical infrastructure is aesthetically more appealing and can be more reliable than overhead lines. Underground systems have about one-third the failures of overhead systems, but locating and repairing problems can take twice as long. The main impediment to building underground lines is cost, but a number of new technologies are becoming available and will allow for greater efficiencies and lower costs. Horizontal directional drilling allows conduits to be placed underground without opening trenches. Similarly, high-voltage insulated underground cables are proving to be more durable while cable trenches located in sidewalks and covered by "pavers" are supposedly easy to remove and allow for simple maintenance.

## Cable and Conductor Needs

Materials research needs to be conducted to increase the transmission corridor power density, with the ultimate stretch goal of achieving power densities for cables and conductors of 50 times ACSR by 2025. Areas of materials research should include: lower thermal expansion materials, lighter weight conductors, higher strength conductors, higher operating temperature materials, and second-generation superconducting materials.

By 2010, overhead conductors should be developed to increase the capacity of existing corridors by five times ACSR at current costs.

Other needs include the installation and demonstration of high-temperature, low-sag conductors; in-situ diagnostics of underground cable to assess remaining life; real-time monitoring on long (100-200 mile) lines; qualification standards; and the validation of dynamic thermal circuit-rating (DTCR) technologies for better operations and secure acceptance by RTOs, ISOs, and ITCs.

## Paths Forward

It is evident that the need for enhanced cables and conductors is immediate. Reliability and cost-effectiveness are primary considerations. There is a need to get utility acceptance and use. System monitoring needs to be transformed into knowledge that can improve system operations. There are opportunities for utilities and developers to form teams and consortiums to fund research, support demonstrations, and deliver on R&D specifications. GridWorks can help develop the consortiums, provide funding, coordinate R&D activities, publish reports, and communicate findings and results.

## Table 2. High Priority Technology Needs: Cables & Conductors

| Underground Cables – Diagnostics (<2010) | Enhanced Reliability Security (2007) | Enhanced Capacity (~2010) | Materials Research (2015) |
|---|---|---|---|
| • Develop methodology to assess in situ condition of underground cable<br>- Partial discharge (when energized)<br>- Dielectric strength | | • Need to install real-time monitoring on transmission to determine real time ratings and sag of transmission lines to improve capacities and reliability; and prevent clearances being exceeded<br>- The typical benefit/cost ratio is 25%<br>- The equipment to perform this function exists today and was developed in July 1975<br>- But, need to implement on long transmission lines up to (100 miles – 200 miles)<br>• Develop overhead conductor systems capable of delivering power densities of 5X over that of ACSR at the same total owning and operating cost by 2010 | • Begin research on advanced materials with the goal of delivering power densities for cables and conductors of 50X ACSR by 2025<br>• Undertake materials research to increase the transmission corridor power density |

| Field Tests/ Demos | Standardization (2010) | Cost Reduction (2010-2020) |
|---|---|---|
| • Demonstrate in showcase installation high temperature, low sag conductors (value proposition needs to be included) | • Develop qualification standards for high temperature, low sag conductors<br>- Address reliability<br>- Environmental concerns | • Develop less expensive directional (trenchless) boring technologies for new and replacement installations so that customer satisfaction and reliability are increased (trenchless)<br>• Reduce O&M cost of underground cable, including extra high voltage cables |

## TABLE 3. LOW PRIORITY TECHNOLOGY NEEDS- CABLES AND CONDUCTORS

| UNDERGROUND CABLES – DIAGNOSTICS (<2010) | ENHANCED RELIABILITY SECURITY (2007) | ENHANCED CAPACITY (~2010) | MATERIALS RESEARCH (2015) |
|---|---|---|---|
| • Arcing fault detection/location on underground cables<br>• Need self diagnosing cable to identify incipient failures in underground cable<br>- Dielectric deterioration<br>- On-line monitoring<br>• Establish a standardized program (technology) that proactively examines remaining cable/conductor life (in situ) – build library<br>• Develop and support use of overhead distribution conductor analysis techniques to help determine replacement schedules and options<br>• Develop better cable diagnostics technology that can easily and accurately determine the condition of underground solid dielectric and PILC cables, to improve system reliability<br>• Develop real time fault location technology for underground distribution feeders. Attributes: low cost, easy to integrate with SCADA, easy to retrofit | • Develop a tamper detection system for transmission line towers to improve security<br>• Develop methods to mitigate galloping and aeolian vibration of overhead conductors<br>• Design lines (conductor/structures) for graceful (non-destructive) – failure and fast repair<br>• Further research is necessary regarding the application of a colored dye on the rod which when exposed to moisture will emit a discoloration through the rubber sheath which can be identified via helicopter patrols before the rod chemically reacts and breaks.<br>• Develop self diagnosing or inspection tools to determine end of life for insulating components to assure long term reliability and low cost maintenance of overhead transmission facilities.<br>• Improve reliability and inspection technology for non-ceramic insulators. | • Develop OH conductor to increase capacity of existing corridors by at least 2x with same sag and temperature characteristics as ACSR<br>• Prove out Dynamic Thermal Circuit Rating technologies for better system operations and secure acceptance of DTCR tools and techniques into RTO's, ISO's and ITC's.<br>• Increase power density on existing ROW in cost- and environmentally-effective manner<br>• Need to determine the most practical solution of increasing the capacity of existing A-C transmission by overbuilding A D-C network with under built A-C on the same structure<br>• Develop a new T&D system as easy to site as fiber optic cable<br>• Support development of environmental impact of high temperature OH transmission lines and superconducting cables (e.g., EMF)<br>• Need to address the increased I2R losses and I2X losses that occur with high temperature low sag conductors and effects on increased power requirements that generation must serve, and the effects on voltage collapse | • Develop "high capacity" overhead conductor materials with negative coefficient of thermal expansion<br>• Conduct material research on HTS cable and high temperature conductors to determine life performance<br>• Insulating technology for damaged NCIs |

| FIELD TESTS/ DEMOS | STANDARDIZATION (2010) | COST REDUCTION (2010-2020) |
|---|---|---|
| • Develop and demo advanced underground conductors to retrofit in dense urban environments<br>• Develop/field test devices to safely drop distribution wires under impact loads, i.e., trees/branches in hurricanes, wind storms, ice storms, snow storms<br>• Field test systems for anti-icing/deicing of transmission line ground wires and conductors<br>• Conduct demos on various advanced conductors and develop data base | • Need standardized (plug and play) interface for real-time-rating technologies for control centers and RTO's<br>- Protocols<br>- Interoperability<br>• Develop independent training seminars for selection and use of high temperature, low sag conductors | • Reduce installed cost of high capacity conductor<br>• Reduce the cost and size of conductor monitoring hardware |

## TABLE 4. HOW TO ADDRESS TOP PRIORITY CABLES & CONDUCTORS TECHNOLOGY NEEDS

| TOP PRIORITY NEEDS | 3-5 MOST SIGNIFICANT TECH. CHALLENGES/ KNOWLEDGE GAPS | WHAT ARE THE 3-5 KEY TECHNOLOGIES | 3-5 SPECIFIC TECH. OR FINANCIAL BENEFITS TO GRID OPERATIONS AND PLANNING | WHAT TYPE OF ACTIVITY IS NEEDED? R&D OR D&C | WHAT CAN UTILITIES AND DEVELOPERS DO? | HOW CAN GRIDWORKS SUPPORT? |
| --- | --- | --- | --- | --- | --- | --- |
| ***Conduct materials research to increase the transmission corridor power density with the goal of achieving power densities for cables and conductors of 50X ACSR by 2025*** | • Achieving higher conductivity<br>• Manufacturability-nanocarbon conductors for strength to resistance to current density optimization<br>• Affordability to end user (i.e., cost of materials)<br>• High dielectric materials with long service life | • Superconductors<br>• Improve conventional materials (aluminum, steel, etc.)<br>• Develop novel materials<br>• Complete development of 2nd generation of superconducting tape<br>• Develop materials for next generation of high temperature low sag conductors<br>• High temperatures in the 250 to 400°C range<br>• Coatings for steel need improvement<br>• Lower sag than steel<br>• Find other novel material systems which might enable high conductivity cables/conductors (e.g., carbon nanotubes?) | • Increasing power flow in existing corridors<br>• Easier siting of new corridors<br>• Reliability<br>• Operating total cost | • R&D > 5 years | • Utilities<br>- Fund research<br>- Support demo of technology, when available.<br>• Developers:<br>- Invest in research and<br>- Form Teams | • Fund R&D<br>• Coordinate with developers of materials and superconductivity<br>• Coordinate and co-fund with EPRI, states, others |
| ***Develop overhead conductor to increase capacity of existing corridors by at least 2x with same ACSR characteristics. Achieve power densities 5X ACSR at current costs by 2010.*** | • Find/develop more materials with low coefficient of thermal expansion<br>• Verify long-term life of polymers<br>• Reduce manufacturing costs of these new materials<br>• Connectors<br>• Long lasting (30-40 years) materials<br>• Develop materials with higher capacity<br>• Acceptance by utilities | • Testing methodologies and technologies to prove out these products<br>• Examine alternate construction designs<br>• Explore improved manufacture technologies for core materials<br>• Any of the new composite cables<br>• Sensors<br>• Auxiliary line hardware | • Faster construction by avoiding permitting<br>• Lower costs if structure work minimized<br>• Better customer relations<br>• Facilitates economic development<br>• Lower environmental impact<br>• Higher ampacity<br>• Increased reliability<br>• Eliminate thermal limitations for lines < 300 miles long | • Basic materials research to improve/prove out existing products <5 years<br>• Prove out hardware and connectors <5 years<br>• Begin research on "out-of-the-box" designs<br>• Develop testing technologies, methodologies and facilities <5 years including exploring test methods from other industries (e.g., aerospace)<br>• Independent assessment of Lessons Learned from past/existing demonstrations | • Through consortium seen mandated 35% of performers contribution by utilities towards R&D that is recoverable in rates<br>• Manufacturers to spearhead collaborative research<br>• Manufacturers need to take more risk on potential high impact products<br>• Commitment to implement by utilities if manufacturers deliver on R&D spec.<br>• Change corporate mindset | • Develop the consortium<br>• Funding |

| Top Priority Needs | 3-5 Most Significant Tech. Challenges/ Knowledge Gaps | What Are the 3-5 Key Technologies | 3-5 Specific Tech. or Financial Benefits to Grid Operations and Planning | What Type of Activity is Needed? R&D or D&C | What Can Utilities and Developers Do? | How Can GridWorks Support? |
|---|---|---|---|---|---|---|
| ***Demonstrate/showcase installation of high temperature low sag conductors (include value proposition) and develop application/ methodology for high temperature, low sag conductors. Address reliability and environmental concerns*** | • Analyze/understand resistance/reactance characteristics Increased load factor<br>• Long term life protocol<br>• Training and installation procedure<br>• EMF issues (technical and societal)<br>• Method of construction<br>• Utility acceptance | • Acceptable test protocol<br>• Acceptable installation practice<br>• Evaluate impact mitigation techniques | • Use existing ROW, dollar saving<br>• Avoid permitting save time<br>• Enhance transmission capacity | • Study/analysis on electrical character.<br>• Accelerated thermo/mechanical life testing | • Form working group consortiums<br>• Cost sharing<br>• Offer real world test sites | • Coordinate activities, publish reports<br>• Communicate activities<br>• Provide incentives<br>• Provide enabling R&D |
| ***Develop methodology (diagnostics) to assess in-site condition of underground cables*** | • Basic research on phenomenon<br>• Installation of monitoring to detect degrading condition in real time<br>• Research on recognition of failure signatures | • Low cost sensing and processing<br>• Fundamental work on characterization<br>• Fundamental work on recognition and discrimination of characteristics | • Improved reliability through reduction of unplanned outages<br>• Lower cost through condition based maintenance vs. time-based | • Research | • Fund characterization and detection activities | • Relate need to utilities and to DOE planners |
| ***Install real-time monitoring on transmission to determine real time rating and impact*** | • Low cost sensors that are distributed along the length of the line<br>• A secure low-cost communication means<br>• A cost-effective method for integrating all this data seamlessly into grid operations | • Self organizing sensor networks<br>• New manufacturing technologies to realize “active” cables and conductors | • Improved utilization of existing assets<br>• Improved reliability and contingency management of the power grid<br>• Improved static and dynamic control of primary assets.<br>• Able to fully subscribe to the grid | • Development<br>• Demonstration | • Cooperate<br>• Provide input on desired characteristics<br>• Provide a test bed for demonstration | • Look beyond individual constituent interests, at societal impact, and use that to drive action<br>• Broaden current focus on overhead lines |

# CHAPTER 4. POWER ELECTRONICS BREAKOUT SESSION RESULTS

Power electronics devices hold substantial promise for transforming the electric power system. High voltage power electronics allow precise and rapid switching of electric power to support long distance transmission. Lower voltage power electronics can be used in power distribution, and in the interface between customers and the electric grid. Power electronics are at the heart of the interface among energy storage, distributed generation, and the electric system.

Barriers to the expanded use of power electronics include relatively high costs and a lack of information on their proven performance, reliability, and durability over a period of time in real-world applications. While power electronics devices can be applied in place of traditional power devices such as switches, controllers, capacitors, and condensers, they have the capability to perform several of these functions within a single device. This capability presents numerous opportunities for expanding functionality and improving system operations.

Technology needs for power electronics include both near and long term opportunities. Over the next 5-20 years, advances in power electronics technologies could revolutionize many aspects of power system operations and planning, including the expanded use of direct current for both transmission and distribution. While the long-term opportunities are substantial, there are near-term opportunities that need to be explored more intensively than they are today.

### Near-Term Needs

More information on the cost and performance of power electronics in real-world applications is needed to expand the use of them today. This means more field tests and demonstrations of existing prototypes and equipment. This will help utilities and manufacturers to get a better understanding of the value proposition for power electronics. Cost may be somewhat higher for power electronics devices, but in many applications these costs can be offset by improved performance and expanded functionality. Field tests will also be helpful to manufacturers in identifying problems and making corrections in advance of product scale-up. This will help to verify and validate product performance and possibly lead to reductions in costs and improvements in reliability.

There are several near-term target applications for power electronics. One is the concept of a grid “shock absorber.” This involves applying power electronics devices for the grid to respond better to large power oscillations and achieve better fault current management. Another near-term application to consider is power flow management. This includes devices for changing the phase angle on AC transmission and control methodologies for power converters to address loop flow and other issues.

A significant near-term need is for a national power electronics test facility. This would be a place where utilities and manufacturers could evaluate performance on power electronics devices and conduct tests of a variety of parameters under a range of operating and environmental conditions. It could be housed at a national laboratory or university.

## Long-Term Needs

One of the most basic power system devices is the switch. A top priority technology need is for power electronics switches with the capability for high voltage, high frequency, and high current and power density operations, with little or no cooling requirements, and a favorable cost-to-value relationship. This will require more research into the properties and suitability of advanced materials. There is interest in exploring new materials; “going beyond silicon.” Diamonds and silicon-carbide are promising materials for use in power electronics.

There is also a need to scale-up and bundle power electronics devices from low voltage to high voltage applications, with expanded capabilities to perform a variety of power system functions related to managing power flows across the grid, and incorporating information exchange for detecting and responding to operational problems. Meeting this need will involve development of “building block converter units” that are easy to install in series or parallel, have standardized grid interface and control software, and include communications systems for remote diagnostics and controls by grid operators.

A key target device, over the long-term is the solid-state transformer with added functions and capabilities. This includes pole-top transformers for electric distribution systems, and larger units for transmission and sub-transmission applications. Such devices would not involve the use of magnetic fields thus having the potential to reduce reactive power requirements. Expanded functions potentially include direct current power transmission, broadband telecommunications, load control, and automated meter reading.

## Paths Forward

Addressing these needs obviously involves expanded funding and stronger public-private partnerships. The GridWorks activity could play a critical role in facilitating information exchange among existing efforts in power electronics for power transmission and distribution applications by utilities, manufacturers, national laboratories, and universities. There are also opportunities for GridWorks to co-fund top priority needs such as the development of a national power electronics test facility or in research in new materials to improve reliability, durability, and the cost-value proposition.

## Table 5. High Priority Technology Needs: Power Electronics

| Need to Accelerate Market Acceptance | Need for Better Power Transmission Systems | Need for Better Power Distribution Systems | Need for Improvements in PE Devices and Equipment |
|---|---|---|---|
| • PE test facility to verify performance<br>• More "beta testing" projects with PE applications<br>  - More funding for demos | • Control of PE with wide area measurement systems<br>  - Information systems | • PE-based transformer with added functions and capability<br>• Automatic grid interconnection of distributed resources, with fault management and islanding<br>  - To isolate customers when distribution is open or shorted<br>  - Load shedding scheme for DG resources i.e. relays, switches, and faster 3-6 cycle | • HV, HF, HT, HR power switch technology – cost, reliability, performance<br>  - Reduce losses<br>  - New material<br>  - Reduce cost by increasing "per unit" capability – increase power density<br>  - Reliable affordable ideal (HV, HC, High efficiency<br>  - Silicon for power and beyond silicon semi-conductor switches<br>  - Solid state DC breaker<br>• Building block converter units that are easily put in series or parallel<br>  - Transformerless<br>  - Modular standardized power electronic grid interface for power system components<br>  - Standardize converter design to increase quality and reduce cost<br>  - Assembled in building blocks for multiple functions<br>• Real time control for multiple converters on the grid. Need to find ways to coordinate them, i.e. devices to improve transient stability |

## Table 6. Low Priority Technology Needs: Power Electronics

| Need to Accelerate Market Acceptance | Need for Better Power Transmission Systems | Need for Better Power Distribution Systems | Need for Improvements in PE Devices and Equipment |
|---|---|---|---|
| • More utility engineers familiar with PE – overcome resistance<br>• Clear metrics to quantify the benefits of PE to the grid<br>• Cost competitive PE converters (HVDC, FACTs, etc.) versus traditional options<br>• PE-related software version control creates problems in operations | • Achieve grid power flow control and congestion management at cost comparable to industrial and commercial power converters<br>  - Device to change power angle on AC transmission<br>  - Power flow control methodologies for power converters for loop flow, etc.<br>• PE-based grid shock absorbers – better response to large power oscillations, and fault current management<br>• System level HV transformer design to minimize hysterisis/ winding loss – $I^2X$ losses<br>• Help for stopping cascading outages<br>  - Prevent voltage collapse<br>• Work on optimal dispatch of PE controllers<br>• Improve FACTS reliability- Protection of FACTS devices from near faults | • PQ ride-through capability for customers<br>  - Several cycles<br>  - Low-cost dynamic voltage restores<br>• Controllable PE switches that operate at 12-69 kV and subcycle response that costs under $100/kW (allows microgrids)<br>• PE for distribution-level clean power quality (unity power factor)<br>• Develop load and fault coordination methodologies that use the "enhanced" dynamics of power electronics<br>• PEs that can recognize whether DGs are grid connect/stand alone and provide VAR/power | • PE reliability needs to be better<br>  - 4 nines<br>  - Passive components<br>• Automatic diagnostics of components to prevent unscheduled downtime and improve reliability<br>• Improve thermal management specifically heat transfer capability (perhaps with heat recovery)<br>  - Minimum cooling requirement<br>• Simple magnetic interface with the grid<br>• Augmentation of transformers, cables, and other components with power electronics<br>• If we achieve PE goals, what would "ideal" grid look like<br>• Medium voltage solid state recloser to limit fault current and transients |

## TABLE 7. HOW TO ADDRESS TOP PRIORITY POWER ELECTRONIC TECHNOLOGY NEEDS

| TOP PRIORITY NEED | TECHNICAL CHALLENGES/ KNOWLEDGE GAPS | BENEFITS TO THE GRID | KEY TECHNOLOGIES, SUBSYSTEMS, COMPONENTS | TYPE OF ACTIVITY | WHAT UTILITIES AND DEVELOPERS CAN DO | WHAT GRIDWORKS CAN DO |
|---|---|---|---|---|---|---|
| **Near-Term Technology Needs** | | | | | | |
| ***Integration of PE Devices with Power Systems (ASAP)*** | • How devices operate under real-world conditions<br>• Total costs of ownership, reliability, durability<br>• Fault management<br>• Incumbent solutions are known and proven<br>• Grid shock absorber<br>• - How minimize customization through standardization | • Higher asset utilization<br>• More capacity through existing infrastructure<br>• More flexibility in siting generation<br>• Better fault management<br>• Improved contingency management<br>• Enables more competitive markets and lower costs to consumers | • Traditional devices: phase shifting transformers, series capacitors<br>• Series static synchronous condensers<br>• Unified power flow controllers<br>• Energy absorption devices | R&D – 3-7 years<br>• Grid shock absorbers<br>• PE cost reductions<br>• PE reliability improvements<br><br>D&C 1-3 Years<br>• Evaluate congestion management at several utilities | • Participate on RD&D advisory boards<br>• Host beta tests<br>• Engage ISOs/RTOs<br>• Identify PE applications in expansion planning | • Build test facility<br>• Cost-share beta projects on continuous basis<br>• Raise awareness about PE<br>• Leverage resources and facilitate collaborations |
| ***Development of National PE Test Facility*** | • Location to site the facility[3]<br>• Identifying managerially and technically qualified operator<br>• Range of power/voltage levels | • Mechanisms to "shake-out" problems<br>• Provide confidence to utilities<br>• National site saves individual utilities from building their own<br>• Accelerates market acceptance<br>• A single location for testing and results shared with members | • Utility-scale converter and protection/isolation<br>• Control system/operator interface with significant simulation component<br>• Energy storage<br>• Balance-of-system – disconnects, filters, transformers<br>• Flexibility to test future devices<br>• SiC communication technology<br>• Products to test from utilities | • Bridges gap from R&D to commercialization<br>• Build now, use for long term | • Donate equipment and manpower<br>• Provide applications specifications<br>• Provide utility system specifications<br>• Use the facility | • Fund development of the facility and cover some operating costs<br>• Make test results public but protect proprietary aspects, when needed<br>• Find co-sponsors (e.g., DOD, DHS) |

[3] If located at a national laboratory, the facility would be MW scale, involve a local utility. If located at a university, it would be kW scale (for student safety), have lower operating costs, provide students with training for future careers in power systems.

| Long-Term Technology Needs | | | | | | |
|---|---|---|---|---|---|---|
| ***PE Power Switches (High Voltage, Frequency, Current) at Competitive Costs*** | • Achieving further increases in voltage, current, and frequency using silicon<br>• Increasing current in new-material-based device<br>• Reduce cost while increasing yield<br>• Understanding materials properties and transport<br>• New physics<br>• New phenomena (high frequency) | • Better PEs (cost, reliability, capacity, functionality)<br>• Better controllability of the grid<br>• Higher grid asset utilization<br>• Lower cost electricity to users<br>• Better power quality to users<br>• Prevent blackouts<br>• Improve system stability | • #1Gen IV ETO (4500v, 6000v, 4000A, 1-3KHz)<br>• #2 Gen V ETO (10kV, 500 Hz)<br>• #3 10kV, 20 Hz, SiC ETO<br>• #4 10kV, 20kHz, diamond (emission) diode (advanced thyristor)<br>• Power flow control<br>• FACTS devices | • #1 = R&D and D&C<br>• #2 = R&D<br>• #3 = R&D<br>• #4 = R&D | • Support R&D and D&C (leverage with existing funding from EPRI, TVA, DOE)<br>• Propose to public utility commission to recover R&D costs in rates<br>• Work together | • Co-fund R&D and D&C<br>• Leverage other R&D (states, EPRI, TVA, etc)<br>• Leverage DOD investments<br>• Leadership |
| ***Building Block Converter Units*** | • Size and topology for transmission-level and distribution-level applications<br>• Switching frequency<br>• Integration of building blocks<br>• Grid interface designs<br>• Thermal management-enhanced cooling techniques for the switches including cryocooling or other active cooling methods besides air.<br>• Materials<br>• Low-cost device designs for DC power systems<br>• Plumbing<br>• Controls<br>• Standards<br>• Reliability of capacitors | • Flexibility<br>• Plug & Play<br>• Reliability and availability<br>• Lower cost operations and maintenance<br>• More favorable costto-value proposition<br>• Cost-effective FACTS<br>• Integration of DG DC customer systems.<br>• Digital control of interchange<br>• Lower loop flows<br>• Reduce spares inventory | • Power semiconductor switch<br>• Mechanical structure<br>• Control, communication, and protection<br>• DC Customer systems<br>• DG integration-voltage regulators<br>• Switches with lower operating temperatures<br>• Standard control algorithms<br>• On-board driver controls<br>• Heat transfer technologies<br>• Better dielectrics and capacitors | • R&D<br>• Test facility<br>• Field demonstrations | • Share costs<br>• Host field demonstrations<br>• Help commercialize<br>• Develop specifications and define operational characteristics<br>• EPRI leadership<br>• Embrace power electronics | • Co-funding<br>• Facilitate collaborations<br>• Promote activities in Office of Science |

| | | | | | | |
|---|---|---|---|---|---|---|
| ***Solid State Transformers with Added Functionality*** | • Failure mode (fails high)<br>• Materials capabilities<br>• EMP vulnerability (security)<br>• Need to re-think system design (high and low sides)<br>• Need better switch<br>• Lower costs<br>• High frequency, high power design<br>• Intelligent control | • Better power quality<br>• Facilitate demand response<br>• Infinite VAR support<br>• Eliminate relays and breakers<br>• Reduce fault current<br>• No oil<br>• Enable system redesigns<br>• Manage spares inventory<br>• Size and weight reduction<br>• Reduce labor costs | • Materials<br>• Secure communications channels<br>• Building block converter unit<br>• Semi-conductor research<br>• High voltage power device module<br>• High voltage power converter/inverter layout and packaging.<br>• Intelligent controller for multilevel AC-DC, DC-DC, DC-AC | • R&D | • Co-fund R&D<br>• Commit to standardization<br>• Communicate specifications to research community<br>• Identify applications | • Co-fund R&D and demos.<br>• Lead materials research<br>• Initial focus on distribution (e.g., develop 4600/220 that is 99.99% reliable and fails open)<br>• Explore EMP resistant/ hardening<br>• Coordinate with DHS and DOD |
| ***Automatic grid interconnection devices for distributed resources*** | • Understanding the dynamics and adopting corresponding measures to solve the problems<br>• Developing the necessary building blocks with critical business value propositions<br>• Establishing a golden UIAL quadrilateral partnerships- Utility, Industry, Academia, Laboratory | • Address connection, ease of power flow regulation<br>• Coordinated fault management<br>• Can add premium for supplying quality power | • Utiilty interaction of power electronic equipment<br>• Hardware (power an accessories) and software (control and communications<br>• Power devices that support HV withstanding capability and faster switching | • Development | • Work together | • Facilitator to proliferate these ideas. |
| ***Control PE with wide area management systems*** | • Better understanding of power system dynamics<br>• Development of remedial actions that can be initiated to prevent major disturbances | • Avoidance of blackout type disturbances | • Missing telecommunication infrastructure | • | • Collaborative research | • Facilitate and promote participation of vendors and utilities<br>• Organize cost shared projects where utility share costs and benefits |

# CHAPTER 5. SUBSTATIONS AND PROTECTIVE EQUIPMENT BREAKOUT SESSION RESULTS

Substations and protective equipment are staples in the electric power system. They are responsible for stepping down and routing the voltage delivered from the power plants to the end user. Typical technologies found in a substation include transformers, feeder lines, capacitor banks, switches, and breakers, and more recently communication devices and software have been integrated with the conventional devices. The majority of substations and the individual substation components are aging and/or are not utilized as assets as effectively as they could be (overused and/or underused). A substation represents a major security asset because of the key power system components within its physical structure and mission-critical communication devices. A loss of substation power delivery components can result in a loss of power affecting thousands of people. Loss of increasingly interdependent communications can lead to possibly less severe immediate losses, but can prevent recognition of developing or incipient power system problems and failures, and prevent rapid recovery from outages.

Substations and protective equipment usually have a large environmental footprint and consist of high-cost capital equipment, making the components hard to replace. One of the challenges that system operators face is utilizing current assets more efficiently, so they extend the lifetime of the equipment and avoid needing to replace the heavy, high-cost equipment. Another challenge is there are no modular, inexpensive, and reliable "next generation" technologies. In addition, next generation equipment must be integrated seamlessly into both the substation and the whole electric delivery system. Security threats, both physical and cyber, present a new challenge for utilities to protect their systems. A lack of standardization of the components and the larger system hinders the process of integrating next generation components and security measures into the electric grid.

## Needs

*Asset Management*

In order to use the existing equipment most efficiently, system operators need better operation and diagnostic support tools to identify developing or incipient problems, and for longer-term asset management. These tools include real-time monitoring to increase throughput, real-time load forecasting, and self-diagnostic equipment capable of addressing internal problems such as cracked bushings, contact wear, and loose connections. Integrating these tools with algorithms for asset managers will help manage the growing need to replace and upgrade existing infrastructure and reduce catastrophic failures, maintenance costs, and improve the overall reliability of the systems.

Reliable and cost-effective sensors are needed for diagnostic use and to enable decision support tools. The sensors must be non-intrusive, capable of surviving in high voltage environments, and inexpensive. A standard data protocol will help to integrate the sensors with current decision support tools. There are many different types of sensors – e.g., infrared, gas analyzers, nanotubes – that need to be developed to address the various components of the subsystem. In cases where sensors are not immediately available, due to unavailability, or insufficient deployment penetration of new embedded sensor components, operating experience, test results, forensic analyses and/or data mining of new data bases can be used as an interim surrogate for future embedded monitoring (e.g. initiatives for existing cable through EPRI, NEETRAC and others)

*Next Generation Equipment*

There is a need for cost-effective fault current limiters to avoid replacing underrated equipment, improve overall power quality, and easily integrate new generation equipment with the current system. Fault current limiters can help protect FACTS devices from near faults, reduce the impacts on other equipment of faults that are felt through the system, and enable open access to the system for energy storage and distributed generation devices. Power electronics and high-temperature superconductivity are some of the next generation technologies that can be integrated to limit fault currents.

In addition synergies may be achievable between technologies to improve their combined performance. For example, the combination of a fault current limiter with a superconducting cable could mitigate post-fault cable recovery time and allow reduced designed size of a superconducting cable to support replacement of conventional cables with higher capacity superconducting cables within existing ducts.

Transformers today are big, overused, and expensive making them difficult to replace. Smaller, lighter, cost-effective, environmentally friendly transformers are needed to lower costs and improve the reliability of substations in the electric grid. Improved materials that are needed to enable next generation transformers include higher saturation flux density core steel, high-temperature insulating materials, and improved dielectric materials.

*Standards*

There is a need for standards across the board – individual components for modularity, protocol for all intelligent electric devices, state-of-the-art substation designs and enhancements to exploit digital information availability, as well as improved tools and techniques to prioritize and filter data and turn it into manageable beneficial business information. Standards will give equipment manufacturers the guidance they need to produce the components and utilities the comfort of knowing that equipment and communication protocols meet appropriate requirements. A substation laboratory and "test bed" are needed to help validate and develop standards for individual components, communication protocols, and integrate components into the system.

## Paths Forward

There are many demands placed on today's substations and protective equipment. This equipment is vital for safe, reliable, and inexpensive delivery of electricity to consumers. Many of these needs can overlap one another and/or a component of another "bigger" picture need. The GridWorks program can provide a vehicle to coordinate and communicate industry activities to proactively encourage integration of these technologies into substation and protective equipment designs and maximize synergies, values and benefits. This will allow stakeholders to have a menu of RD&D activities that are taking place, engage in a dialogue to clearly communicate needs and expectations to other stakeholders and can find potential opportunities to collaborate.

## Table 8. High Priority Technology Needs: Substations and Protective Equipment

| Asset Management | Next Generation Equipment | Security | System Integration | Standardization |
|---|---|---|---|---|
| • Operation and diagnostics decision support tools for asset management<br>- Real-time primary equipment monitoring and diagnostic devices to increase throughput<br>- Real-time load forecasting at the sublevel<br>- Inexpensive substation equipment capable of self-diagnostics of internal problems (contact wear, loose connection, cracked bushings)<br>- Develop diagnostic measurement systems that can be coupled with advanced, real-time programs to prohibit system behavior to assure availability<br>- Develop integrated real-time monitoring/diagnostic systems for power transformers<br>- Load flow stability contingency in better than real time<br>• Develop low -cost sensors for diagnostic use of substation equipment | • Develop cost-effective fault current limiters<br>- Implement fault mitigation (limiters)<br>o Enable "open access"<br>o DG<br>o Energy storage<br>o Protect FACTS devices from near faults<br>o Improve superconduction<br>o Reduce "through faults" impacts on infrastructure<br>o Substation HV circuit breakers<br>• Develop transformers<br>- Increase expected life of HV and EHV<br>- Standardized/flexible power transformer designs with better instrumentation/data<br>- Improve manufacturing of steel core to reduce costs and losses through modeling and processing<br>- High saturation core steel<br>- Increase efficiency<br>• Solid-state transformers | • Develop standard cyber security method/equipment to allow secure and reliable supervisory control<br>- Build in security measures in design of new critical substation/ transformer<br>- Develop and implement intrusion detection systems | • System operation – DG micro/macro grid configuration at substation – auto control and dispatch (autonomous) demo<br>- Standardize DG substation system for stationary and mobile application at the substation distribution side of feeder<br>• Controlled regional islanding – special protection schemes | • Implement standards<br>- Products<br>- Modularity of systems for economy<br>- Adopt international standard protocol for all IED devices<br>- "Standard state of the art substation design used so template or guide for industry – best with today"<br>- Standards for substation design for lower costs |

## Table 9. Low Priority Technology Needs: Substation and Protective Equipment

| Asset Management | Next Generation Equipment | Security | Communication | System Integration |
|---|---|---|---|---|
| • Develop technologies to add incremental capacity to power transformers<br>• Enable renewable economies and better subsystem asset utilization with load cycle (e.g., 8 hour) energy storage<br>• Implement condition based monitoring and asset management via wireless sensors, algorithms, and linkage to work order systems and life management<br>• National "spare" apparatus system<br>• Robotic intelligence (Design and develop)<br>• Better understanding of limits of existing components for operating above nameplate conditions | • More MVA per square foot for urban substation designs<br>• Self-healing components of systems<br>• Improved performance of insulating materials for high temperatures application and improved thermal management | • Physical<br>- Design for security (civil engineering) | • Real-time communication capability of information captured – transmit to a remote location for control and protection | • Substation automation interfacing part of EMS<br>- Demonstrate, commercialize, digital process bus as interface between station sensors and IEDs (plug and play)<br>- Automated data analysis<br>- Modal sharing for configuration management of separate models<br>• New protective relay schemes that limit the dependency on over-reaching impedance relays (e.g., Zone 3) to improve interconnected reliability<br>• Develop fault detection equipment and systems to assist in management and recovery from off-normal conditions<br>• Design centralized relaying centers |

## TABLE 10. HOW TO ADDRESS TOP PRIORITY SUBSTATION AND PROTECTIVE EQUIPMENT TECHNOLOGY NEEDS

| TOP PRIORITY NEED | TECHNICAL CHALLENGES/ KNOWLEDGE GAPS | BENEFITS TO THE GRID | KEY TECHNOLOGIES, SUBSYSTEMS, COMPONENTS | TYPE OF ACTIVITY | WHAT UTILITIES AND DEVELOPERS CAN DO | WHAT GRIDWORKS CAN DO |
|---|---|---|---|---|---|---|
| ***Low cost sensors for diagnostic use that are embedded in the equipment and integrated with decision support tools.*** | • Non-intrusive sensors for easy retrofit for transformers and breakers<br>• Hardening sensors for high voltage environment<br>• Inexpensive gas analysis for transformers and cables<br>• Standard data protocol<br>• Key predictive attributes/signatures to monitor durability in applied environment cost of installation | • Increased capacity<br>• Improved reliability<br>• Reduced maintenance cost<br>• Reduced outage time<br>• Prevent catastrophic failures.<br>• Reduced operating margins. | • Infrared<br>• Acoustics<br>• Solid state gas analyzers<br>• Vibration<br>• Optical CT/PT<br>• Optical temperature sensor<br>• Nanotubes<br>• Wireless power line/splice temperature sensing<br>• Database of key signatures connection to system alarms. | <u>R&D – 3-7 years</u><br>• Applied engineering<br>• Nanotubes<br><br><u>D&C 1-3 Years</u> | • Develop business case<br>• Participate in demo projects<br>• Utilities as advisors- defining the needs<br>• Drive standards<br>• Labs can use LDRD<br>• Utility R&D<br>• Support the EPRI program | • $<br>• Coordination of direction and priorities<br>• Drive standards<br>• Facilitate technical exchange<br>• Conduct workshops for defining needs<br>• Assist in developing test beds and demos |
| ***Transformers with increased life expectancy, flexible and better integration with data, and improved high saturation steel core Also smaller, cheaper, lighter, overloadable without loss of life and environmentally friendly*** | • High saturation flux density core steel, low loss<br>• High temperature insulating materials<br>• Improved dielectric materials<br>• Cryogenic systems for HTS<br>• Voltage regulation<br>• Losses<br>• Power electronics<br>• New materials in transformer construction to replace paper insulation<br>• New insulating fluids (low cost and environmentally friendly)<br>• Lower cost 2G conductors<br>• Lower cost cryocoolers<br>• No standards<br>• Conform to all different voltage levels and requirements<br>• No one in the U.S. is building these devices | • Lower capital cost<br>• Lower operating cost<br>• More transportable<br>• Design standardization<br>• Reduced space requirements<br>• Seamless power exchange and instant VAR regulation<br>• Greater loading on transformers<br>• Ability to site indoor and outdoor<br>• Safe- no fire hazards and environmentally friendly (no oil spills)<br>• Energy efficiency<br>• Fault current limiting | • HTS<br>• Materials<br>• Heat transfer<br>• Solid state transformers<br>• Tap changers<br>• Near lossless power electronic switch<br>• Petro industry challenges have led to insulation material breakthroughs<br>• Dielectric materials and insulation design. | <u>R&D– 3-7 years</u><br>• Materials (dielectric/ magnetics)<br>• Power electronics<br>• HTS<br>• Thermal management<br><br><u>D&C 1-3 Years</u><br>• Alpha/beta field demo<br>• Standardization | • Prototype develop<br>• Develop requirements/ specs<br>• Field demos | • Support core R&D<br>• Facilitate demo partnerships<br>• Facilitate standards development through suppliers<br>• Enhance national security through domestics<br>• Emphasize new transformer concepts<br>• Develop new insulating materials |

| Top Priority Need | Technical Challenges/ Knowledge Gaps | Benefits to the Grid | Key Technologies, Subsystems, Components | Type of Activity | What Utilities and Developers Can Do | What GridWorks Can Do |
|---|---|---|---|---|---|---|
| ***Fault current limiters that are cost-effective, enable "open access, reliable, efficient, tunable, standardized commercialized packages and include solid state, high voltage devices*** | • Very fast response<br>• Energy absorption<br>• Reset/Recovery time<br>• Dielectrics at High voltage<br>• Materials research<br>• Single point failures, design complexity, and unproven technology<br>• Power electronics | • Avoid replacing underrated equipment<br>• Improved power quality<br>• Easier incorporation of new generation technology<br>• Paradigm shift<br>• Lower reactance generator and transformers<br>• Slower fault clearing requirements<br>• Transient stability benefits<br>• Higher throughput<br>• Standard substation designs | • High temperature superconductivity<br>• Magnetic saturation<br>• Power electronics<br>• Inductive current rate of change<br>• Active resister insertion | • R&D and D&C | • Prototype testing<br>• Alpha/beta field demo<br>• Determine benefits and device design criteria | • Coordinate/fund technology specification/standards development<br>• Bring appropriate parties to the table<br>• Core R&D funding for barriers/alternatives |
| ***Decision support tools for asset management*** | • Cost effective sensor availabilities and strategies for equipment and systems<br>• Algorithms for filtering, prioritizing and input to work processes<br>• Open architecture modeling, interoperable, user configurable software tools to implement overall asset management and condition based monitoring as incremental value added.<br>• Better than real-time operation of load flow, contingency stability software<br>• Model sharing capabilities<br>• Materials deterioration measurement<br>• How to use available technologies to manage assets<br>• Industry failure component database (including duty, environment, through fault histories) | • Just in time maintenance and out of service<br>• Reduce catastrophic failure<br>• Reduce maintenance costs<br>• Reduce the impact of reliability events<br>• Cost and span of cost savings over increasingly aging infrastructure<br>• Prevent complexity from other wise impacting reliability.<br>• Life cycle cost of software and operations tools.<br>• Superior control of grid operations<br>• Improved efficiency, reduce the need for new generation | • Cost-effective wireless sensors for widely available anomalies and exception measurements<br>• Cost-effective communication architecture and equipment with appropriate continuity and reliability<br>• CIM/UCA Standards and support and implementation<br>• Database similarity<br>• Modular equipment<br>• Model sharing<br>• Communications<br>• Version control s tandards for software and IED's<br>• Understanding of insulation deterioration process<br>• Meta-level computer control, access, coordination<br>• Switching, control, and leveling hardware at various levels in grid hierarchy | • R&D for all areas following by D&C<br>• Selected government funding for R&D<br>• Standardization and cross-industry applications facilitated by government | • Participate with government in development of standards<br>• Create consortia for selected pieces.<br>• Focus on areas of stability | • Provide overall context and priorities<br>• Provide standardization by supporting forums<br>• Selected funding for challenges of highest value and most stakeholders.<br>• Determine availability of current technologies that address the needs. |

| Top Priority Need | Technical Challenges/ Knowledge Gaps | Benefits to the Grid | Key Technologies, Subsystems, Components | Type of Activity | What Utilities and Developers Can Do | What GridWorks Can Do |
|---|---|---|---|---|---|---|
| ***Standards for products, modularity; international protocol for all IED, devices, state-of-the-art substation designs*** | • Substation system integration standard/guide- digital equipment, sensor integration, and DG integration<br>• Standard for intentional islanding at substation level<br>• Substation micro/macro grid system standard<br>• Functional substation design for compatibility of solid state devices with existing equipment.<br>• Standard for substation equipment and subsystem IED | | • Standard for integration of devices, components, and subsystems for substation autonomous operation.<br>• Standard for substation islanding switch (high power - fast, less than ½ cycle)<br>• Substation system control module. | | | • Substation lab to validate develop standard substation=- digital equipment, sensor integration, DG integration, and micro/macro grid<br>• Drive industry collaboration for standards development (IED, Digital equipment) for substations<br>• Drive standard development for substation islanding switch |
| ***Demonstration of DG / microgrid configuration at substation with automatic control and autonomous dispatch*** | • Communications between devices.<br>• High frequency, high band-width access with the substation and to other substations | | • | • Development | • Address one problem at a time<br>• Develop a matrix of gaps that need to be worked on first | • Work with utilities on tasks |
| ***Special protection schemes to manage islanding*** | • Do we really know protective relaying will work?<br>• Does the Eastern interconnect need to be designed differently (i.e. split up into smaller more manageable sections) | • Prevent another NE blackout | • Improved modeling<br>• Power electronics to help solve the cascading problem<br>• Improved data communication between utilities and RTOs | • Development | • | • Become more involved in regional planning to better understand issues and opportunities.<br>• Promote technologies that would improve grid stability |

# CHAPTER 6. CONCLUSIONS

## Cross-Cutting and Additional Needs

Based on the material delivered or developed at the workshop, several crosscutting themes and creative opportunities emerged. These areas of potential research, development or demonstration are provided below, along with descriptions of potential roles DOE may choose to follow in developing a roadmap for GridWorks.

### *Create sensors that apply to cable and substation diagnosis*

Many of the parameters to be monitored were the same in various applications; i.e. temperature, voltage, amperes, gas constituents, waveform, etc. It would seem that a combined effort to define a group of appropriate sensors and the creation for varied applications on substation and line equipment would be beneficial and economically advantageous.

### *Develop methods that translate massive data to instructions*

To make decisions and to maintain the system in this new environment data will need to be converted into intelligence and instructions. The most advantageous outcome would be an automated approach that would deliver human factor oriented instructions to utility crews and operators in real time.

### *Evaluate material science support for all aspects of GridWorks*

Some of these materials need to have lower electrical resistance; others need the opposite capability to act as a switch. The desire for new industrial materials with an array of thermal, mechanical and electrical properties was discussed in various applications.

### *Plan GridWorks demonstration to repair storm damage*

One possible approach would be the development of a plan with willing electric utilities to have a new grid design with single or multiple advanced components ready for construction when a storm damages existing facilities. The new line and equipment would then be able to be built and operate in place of the previously destroyed system. If this were to be arranged with a public power or cooperative utility there would likely be arrangements to conclude before construction with the USDA Rural Utility Service and the Federal Emergency Management Administration.

### *Explore new technology for solid-state switches*

Currently the majority of solid-state switches are based on silicon technology. This approach has worked effectively and advanced rapidly in the computer and electronics industry as demonstrated by the general adherence to Moore's Law. The issues of resistance and heat are a major factor. The small number of customized applications is also a factor contributing to slow development. New materials should be explored since they seem to hold greater promise for effective development.

*Evaluate latency issues in collecting data from long lines*

This array of equipment would need to communicate to some set of data accumulation or reporting devices to allow real time control of the grid system. Since the speed of the electrons supplying service to distant locations is nearly the speed of light, any communications latency would be a major obstruction to the operators and maintenance staff.

*Build devices with physical and cyber security incorporated*

Virtually every aspect of the GridWorks program should consider grid security as a basic requirement. Since most of the equipment to help make the grid of the future operate has not been designed at this point factoring these components into the basic design criteria would be advisable. Uniform software protocols and configurations would also help equipment manufacturers and operators to be capable on several platforms and in numerous ranges of equipment.

*Coordinate software and communications interoperability*

Power electronics and other grid equipment are going to demand communications and software to be able to operate normally and in special stress situations. If each manufacturer has a proprietary approach to collecting, storing and processing data and passing it along to other equipment or central control computers the development of future grid designs could be delayed.

*Design the architecture for a new grid with available equipment*

There have been developments over the last decade or more aimed at supplying the tools and equipment to make the grid more capable and controllable. One of the efforts GridWorks could undertake is the development of an integrated architecture for a new grid using the devices currently available to the industry.

*Design security sensors that apply throughout system*

It seems appropriate to make an effort to develop sensors that would be capable in numerous applications. For instance an oil level gauge could apply to transformers, capacitors and breakers. Sensors to monitor a substation fence for intruders may also be able to track unexpected actions at a lattice tower on a transmission line.

*Model and measure the cost of not changing the system*

In all business decisions the choice to not change a system has financial consequences, as does the decision to make a change. There has been some analysis of the current cost of disruptions in the national transmission grid. There have also been some studies of the cost of disturbance in the distribution system. Some of the current cost estimates are extremely large with a few hours of electrical outage having a regional or national cost that approaches the annual revenue of the electric utility industry.

## Next Steps

The workshop helped introduce the GridWorks program to stakeholders and distinguish the focus between it and the GridWise program. The program also started a dialogue between DOE and GridWorks stakeholders, which is important to continue in the future. Ensuring an ongoing dialogue will help the GridWorks program coordinate and facilitate stakeholders' research on technologies to modernize the grid.

It is essential to ensure information about RD&D activities underway is being regularly exchanged and distributed to a broad audience in order to avoid duplication of efforts. Exchanging information will also allow research leaders to learn of other parties that may be interested in collaborating on projects. GridWorks can help facilitate this exchange by bringing together various stakeholders at workshops or meetings; however, customers need to be represented at future workshops. Stakeholders believe partnerships are important to furthering technological research efforts and needed to leverage the limited funds available.

GridWorks should develop an inventory of existing research, development, and demonstration projects so it is easier to identify various needs and priorities. This inventory could also be used to help determine how to allocate federal funds.

DOE could host follow-up workshops to ensure so stakeholders are not recreating the wheel every time they meet. Specifically, stakeholders would like DOE to host another workshop to discuss the implementation of the ideas generated thus far. It is important to sustain long-term interest in participating in the program.

The aging infrastructure provides a window of opportunity to introduce new technologies, and the time to act on this is now. DOE needs to communicate a sense of urgency regarding accelerating the introduction of new technologies to modernize the grid. It can do this by ensuring the benefits of valuable research projects are published in DOE reports since these reach a large audience and present a balanced viewpoint.

# APPENDIX A: AGENDA

***Sponsored by***
**U.S. Department of Energy**

**Onsite Workshop: October 20-21, 2004**
**Webcast Workshop: October 27-November 3, 2004**

## AGENDA

**October 20 - Day 1**

7:30 am Registration and Continental Breakfast

8:30 am Opening Plenary Session

- Welcome and Overview of GridWorks - *Gil Bindewald, Program Manager, Office of Electric Transmission and Distribution*
- Overview of Electric Power Research Institute (EPRI)/ Electricity Innovation Institute (E2I) related activities –*Terry Surles, Vice President, E2I*
- Overview of Office of Energy Assurance (OEA) related activities – *Hank Kenchington, OEA*
- Overview of Facilitation Game Plan – *Rich Scheer, Energetics, Inc.*
- Q&As

9:30 am Panel #1 – Technical Status of Cables and Conductors Today - *Chair –Herve Deve, Technical Manager, 3M*

- Utility Perspective on Existing Equipment and Functional Requirements - *Chris Hickman, Director of Engineering and Technology, Public Service New Mexico*
- Manufacturer Perspective on Costs and Performance of Existing Products - *Vincent Kruse, Southwire*
- National Laboratory/University Perspective on Existing RD&D - *John Stovall, Oak Ridge National Laboratory*
- Q&A

10:20 am Break

10:35 am Panel #2 – Technical Status of Power Electronics Technologies Today - *Chair – Jim Davidson, Professor, Vanderbilt University*

- Utility Perspective on Existing Equipment and Functional Requirements – *Abdel-Aty Edris, EPRI*
- Manufacturer Perspective on Costs and Performance of Existing Products – *Rana Mukerji, ABB*
- National Laboratory/University Perspective on Existing RD&D – *Stan Atcitty, Sandia National Laboratories*
- Q&A

11:20 am Panel #3 – Technical Status of Substation and Protective Systems (e.g., transformers, switchgear, circuit breakers, surge arresters) Today – *Mladen Kezunovic, Professor of Electrical Engineering, Texas A&M University*

- Utility Perspective on Existing Equipment and Functional Requirements – *John Gasal, Connexus Energy*
- Manufacturer Perspective on Costs and Performance of Existing Products – *Sam Mehta, Waukesha Electric*
- National Laboratory/University Perspective on Existing RD&D - *Richard DeBlasio, National Renewable Energy Laboratory*

- Q&A

12:10 pm Lunch – Regulatory Perspectives on Cost Recovery for New Transmission Investments, Reliability and New Technologies – *Alison Silverstein, Consultant*

1:45 pm Discussion of **"Drivers" Affecting Grid Operations and Planning**

3:00 pm Break

3:30 pm Breakout Group Discussion #1 **RD&D Needs and Priorities**

5:00 pm Adjourn Day 1

5:30 pm Reception

**October 21 - Day 2**

7:30 am Continental Breakfast

8:15 am Breakout Discussion #2 – **RD&D Needs and Priorities**

- includes discussion of roles for each identified need/priority
- includes preparation of summary report

10:30 am Break

11:00 am Closing Plenary Session- **Steps for Sustaining Interest and Building Support for GridWorks**

- Oral reports from each breakout group
  - Top Cables and Conductors Needs
  - Top Power Electronic Needs
  - Top Substation and Protective Equipment Needs
  - Top Cross-Cutting and Additional Needs
- Discussion of gaps, overlaps, crosscutting themes
- Discussion of next steps for sustaining interest and building support for GridWorks
- Final thoughts

12:30 pm Adjourn Workshop

# APPENDIX B: PARTICIPANT LISTS

### ONSITE PARTICIPANT LIST

| Name | Organization |
|---|---|
| Tarek Abdallah | Construction Engineering Research Laboratory |
| Stan Atcitty | Sandia National Laboratories |
| Robert Bari | Brookhaven National Laboratory |
| Jovan Bebic | General Electric |
| Ken Caird | General Electric |
| James Crane | Exelon |
| Jeff Dagle | PNNL |
| Jim Davidson | Vanderbilt University |
| Murray Davis | DTE Energy Technologies |
| Richard DeBlasio | NREL |
| Herve Deve | 3M |
| Deepakraj Divan | Georgia Institute of Technology |
| Matthew Donnelly | PNNL |
| Patrick Duggan | Consolidated Edison of NY, Inc. |
| Aty Edris | EPRI |
| Lavelle Freeman | GE Energy |
| Floyd Galvan | Entergy Corporation |
| John Gasal | Connexus Energy |
| Stephanie Hamilton | Southern California Edison |
| Chris Hickman | Public Service Co. of NM |
| Alex Huang | North Carolina State University |
| Michael Ingram | TVA |
| Kathleen Jones | ERDC-CRREL |
| Henry Kenchington | U.S. DOE |
| Lumas Kendrick | Sentech, Inc. |
| Richard Kent | Bechtel BWXT Idaho, LLC |
| Mladen Kezunovic | Texas A&M University |
| Thomas King | ORNL |
| Ben Kroposki | NREL |
| Dale Krummen | American Electric Power |
| Vince Kruse | Southwire |
| Frank Lambert | Georgia Tech/NEETRAC |

### ONSITE PARTICIPANT LIST (CONTINUED)

| Name | Organization |
|---|---|
| Marc Mahoney | National Grid |
| Madhav Manjrekar | EATON |
| Joseph Mavec | U.S. DOE |
| Shirish Mehta | Waukesha Electric |
| Dennis Mize | Southern Company |
| Blake Morrison | Kinectrics |
| Rana Mukerji | ABB Inc. |
| Phillip Niedzielski-Eichner | Resource Consultants, Inc. |
| Gary Nowakowski | U.S. DOE |
| Phil Overholt | U.S. DOE |
| Dana Parshall | FirstEnergy Corporation |
| Michael Pehosh | NRECA |
| George Rodriguez | Southern California Edison Co. |
| Forrest Small | Navigant Consulting |
| David Szucs | U.S. DOE/NETL |
| Leon Tolbert | University of Tennessee |
| Gunnar Walmet | NYSERDA |
| Paul Wang | Concurrent Technologies Corp |
| Kenneth Watts | Bechtel BWXT Idaho, LLC |
| Randall West | Encorp |

### FACILITATION & CONFERENCE TEAM

| Name | Organization |
|---|---|
| Joseph Badin | Energetics, Incorporated |
| Gil Bindewald | U.S. DOE |
| Daniel Brewer | Energetics, Incorporated |
| Tara Faherty | Energetics, Incorporated |
| Steve Lindenberg | Consultant |
| Richard Scheer | Energetics, Incorporated |
| Alison Silverstein | Consultant |

## WEBCAST PARTICIPANT LIST

| Name | Organization |
|---|---|
| Ram Adapa | EPRI |
| Poonum Agrawal | US DOE |
| Tracy Anderson | 3M |
| Lisa Beard | Tennessee Valley Authority |
| Carl Benner | Texas A&M University |
| Stan Blazewicz | Navigant Consulting, Inc |
| Sachna Bobal | Hydro One Inc. |
| John Boshears | Southwest Power Pool |
| Mia Bosquet | Battelle-PNNL |
| Brian Bowers | Raytheon Company |
| Gustavo Brunello | General Electric Co |
| Richard Burdette | Office of the Governor |
| Gail Carney | Central Hudson Gas and Electric |
| Chris Church | Public Service Commission |
| Chuck Collins | DOE - WRO |
| Lorie Conley | TVA |
| James Dante | Southwest Research Institute |
| David Devendorf | National Grid USA |
| Ian Dobson | University of Wisconsin |
| Karen Dockham | Fl Public Service Commission |
| Emilie Dohleman | Public Service Company of New Me |
| Rick Dong | Epri Solutions |
| Roch Ducey | U.S. Army Engineer R&D Center/CE |
| Mark Dudzinski | General Electric Co |
| Tami Evans | National Grid |
| Eihab Fathelrahman | Pacific Northwest National Labor |
| Blake Forbes | Public Service Co of N.M. |
| Karen Forsten | EPRI PEAC Corporation |
| Richard Fuson | LCEC |
| Lauren Giles | Energetics |
| Joseph Graziano | Tennessee Valley Authority |
| Lynn Greene | Moye Giles LLP |
| John Greenlaw | Western Area Power Administration |
| Spring Haby | Southwest Research Insitute |
| Randy Hale | Nashville Electric Service |
| Ken Hall | Edison Electric Institute |

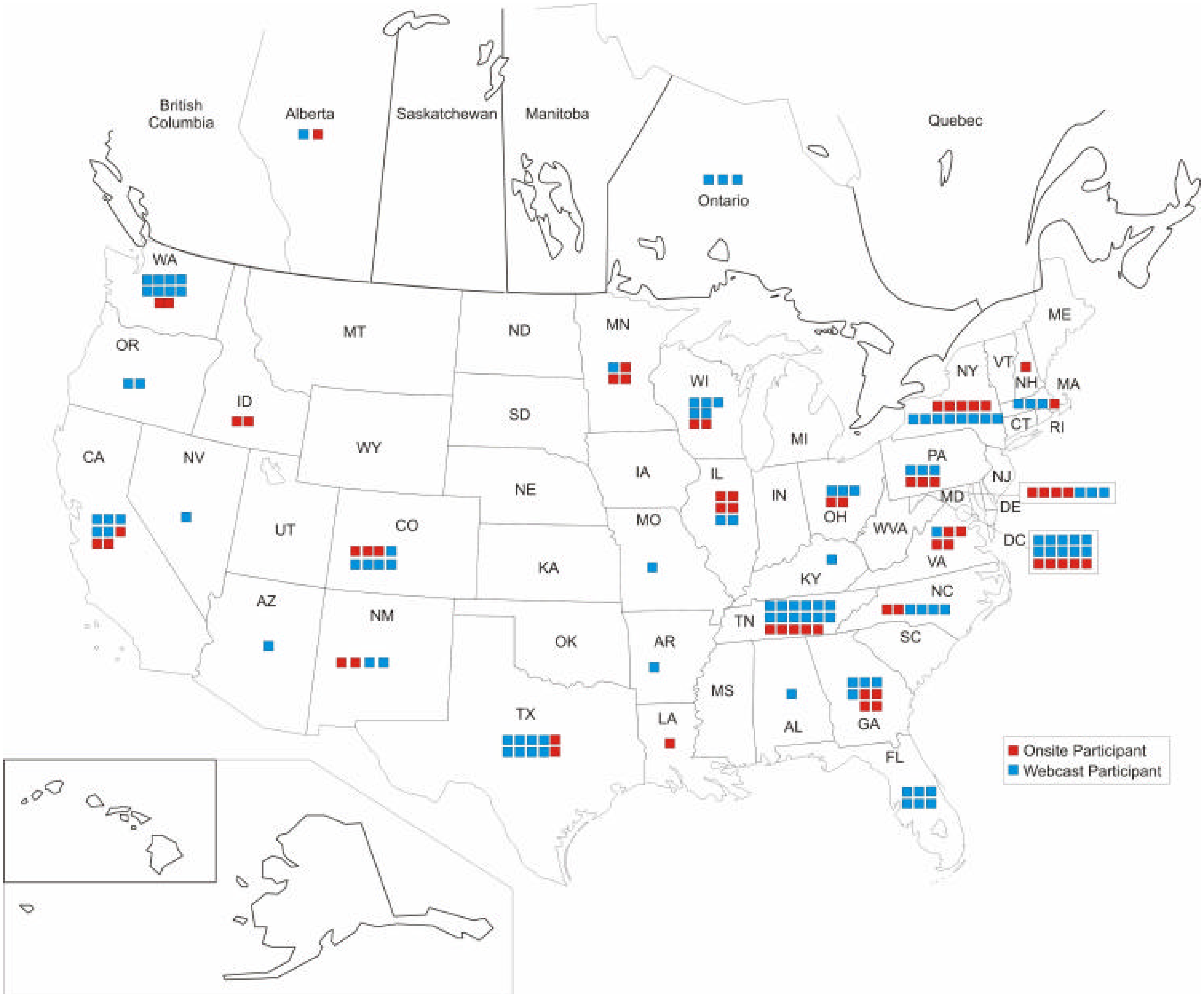
## WEBCAST PARTICIPANT LIST (CONTINUED)

| Name | Organization |
|---|---|
| Donald Hammerstrom | PNNL |
| Debbie Haught | DOE |
| Ralph Hill | Southwest Research Institute |
| Lorne Hillier | American Transmission Co. |
| Mike Hoffman | BPA |
| Patricia Hoffman | DOE, EE-2D |
| Martin Hohl | American Electric Power |
| Eli Hopson | House Science |
| John Howe | American Superconductor |
| Michael Hyland | APPA |
| Dennis Jacobs | Buswell Energy |
| Jeff James | Western Regional Office, U..S. D |
| Matthew Johnson | Sentech, Inc. |
| Ben Johnston | Columbia Water & Light |
| David Jopling | Florida Public Service Commission |
| Thomas Key | EPRI PEAC Corporation |
| David Kiguel | Hydro One Networks Inc. |
| Neil Kirby | AREVA T&D Inc |
| Brian Klepper | Lee County Electric Cooperative |
| Robert Kondziolka | Salt River Project |
| Arthur Kressner | Con Edison of NY, Inc. |
| Soorya Kuloor | Optimal Technologies |
| Jason Lai | Virginia Tech |
| Charles Lawrence | American Transmission Company |
| Glenn Light | Southwest Research Institute |
| Joanna Livengood | DOE |
| Dejim Lowe | TVA |
| Ning Lu | Pacific Northwest National Labor |
| David Lubkeman | ABB |
| Mark Major | Southwest Research Institute |
| Arthur (Art) Mander | Tri-State G&T |
| Brian Marchionini | Energetics |
| Mary Marshall | Southwest Research Institute |
| Benjamin McConnell | Oak Ridge National Laboratory |
| Ralph McKosky | Transmission Technologies |

## WEBCAST PARTICIPANT LIST (CONTINUED)

| Name | Organization |
| --- | --- |
| Lorne Midford | MH |
| Mike Miller | Southern Company Services |
| John Nunley III | Composite Technology Corporation |
| Michael Pearman | Georgia Power Company |
| Andrew Phillips | EPRI |
| Buddy Powers | southwire |
| Rob Pratt | Pacific Northwest National Labor |
| Marshall Reed | DOE |
| Henry Reynolds | American Transmission Co. |
| Larry Rinehart | RMS Power Products, Inc. |
| Tom Rizy | ORNL |
| Bradford Roberts | S&C Electric Co. |
| John Schneider | AEP |
| Ernst Scholtz | ABB Inc. |
| Mario Sciulli | Department of Energy (NETL) |
| Michael Sheehan, P.E. | MicroPlanet LTD |
| Jeanette Sickel | Florida Public Service Comm |
| Harold Simmons | Southwest Research Institute |
| Merrill Smith | US DOE |
| John Stovall | ORNL |
| Peter Sutherland | EPRI PEAC Corporation |
| Louis Szablya | Great Northern Power Development |
| Shanmugan Thamilarasan | Bechtel Power Corp |
| Edward Thomas | Utility Electrical Consultants |
| Darrell Trimble | Nashville Electric Service |
| Jack Varner | Georgia Power company |
| Predrag Vujovic | KEMA |
| Joseph Waligorski | FirstEnergy |
| Bud Wegner | San Diego Gas & Electric Co |
| Scott Wehler | Adams Electric Cooperative |
| Zhihong Ye | GE Research Center |
| Meng Yue | Brookhaven National Laboratory |
| Shalom Zelingher | New York Power Authority |

# APPENDIX C: MAP OF PARTICIPANT LOCATIONS



# APPENDIX D: GRIDWORKS RD&D PARTICIPANTS BY ORGANIZATION TYPE